PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 : G08B 29/00, 13/24, G01B 7/08 G01P 13/00

A1

(11) International Publication Number: WO 89/ 02635

(43) International Publication Date: 23 March 1989 (23.03.89)

(21) International Application Number: PCT/AU88/00363

(22) International Filing Date: 16 September 1988 (16.09.88)

(31) Priority Application Number: PI 4424

(32) Priority Date: 16 September 1987 (16.09.87)

(33) Priority Country: AU

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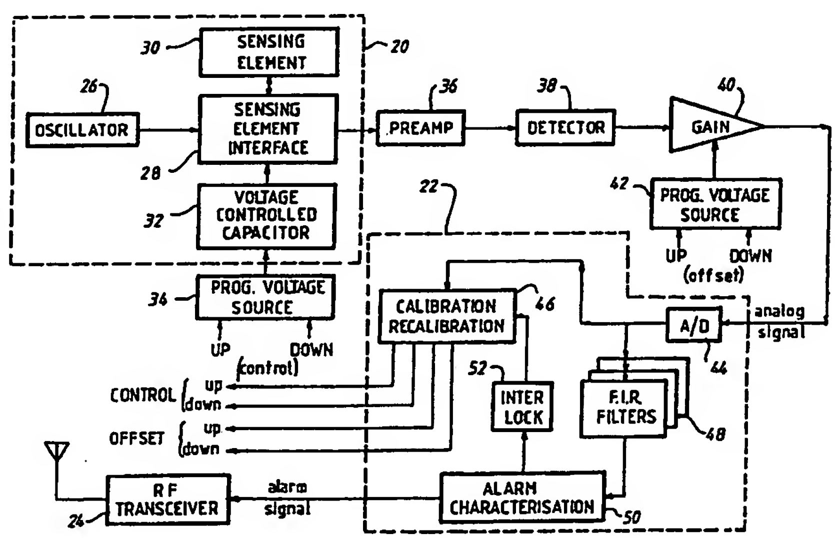
(81) Designated States: AT, AT (European patent), AU, BE (European patent), BR, CH, CH (European patent), DE, DE (European patent), DK, FI, FR (European patent), GB, GB (European patent), IT (European patent), JP, KR, LU, LU (European patent), NL, NL (European patent), NO, SE, SE (European patent), SU, US.

Published
With international search report.

(54) Title: PROXIMITY SENSOR



(57) Abstract

A proximity sensor that employs an electrostatic sensing element (30) driven by an oscillator (26) is described, in which a disturbance of the electromagnetic field surrounding the sensing element is sensed by detecting small variations in the effective capacitance of the sensing element. An artificial disturbance of the field, of the kind the sensor is designed to sense, is discriminated from natural disturbances, of the kind caused by environmental drift, by measuring the effective time rates of change of said disturbance and comparing the measured value to an alarm threshold value. A microprocessor based control device (22) is employed to measure the effective time rates of change of the digital signal, representative of the detected capacitance variations of the sensing element (30), and to provide other control functions for the sensor, such as calibration on start-up and periodic recalibration during normal operation. The sensing element (30) is provided with an interface (28) in the form of a tuned circuit which is maintained near resonance by a voltage controlled capacitor (32). Maximum sensitivity of the sensor to capacitance variations of the sensing element (30) is maintained using a programmable voltage source (34) under the direct control of processor (22). Processor (22) employs a cascade of digital Finite Impulse Response (FIR) filters (48), configured as low-pass filters, to measure the effective time rates of change of the digital signal. A security sensing system is also described in which a plurality of the proximity sensors are controlled by a monitor using an RF communications link.

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PROXIMITY SENSOR

Field of the Invention

The present invention relate to a proximity sensor and more particularly to a proximity sensor of the kind used to sense environmental changes due to the proximity of an object or other disturbance.

The invention has particular utility in security systems for detecting the presence of intruders but may be readily adapted to other uses such as, for example, measurement of dielectric sheet thickness variations. Sensors of the aforementioned kind are known and may be divided into three categories:

1. Electrostatic
2. Induction
3. Radiation

In its preferred form the present invention provides an electrostatic type sensor, but any one of the other two types of sensor could be provided with minor modifications.

Although the following description of the prior art and of a preferred embodiment relates to proximity sensors used in electronic security systems, the field of the invention is not to be restricted to security systems. In this connection, the term "proximity sensor" is to be understood in the broadest sense as a sensor capable of sensing an object, surface or other disturbance near the sensor.

Discussion of Prior Art

It is a continual development within the art of security systems to improve the above kind of sensors to make them more sensitive to the objects or movement which they are designed to sense, and less susceptible to false sensing caused by natural changes such as changes in circuit components due to variations in temperature, humidity or other environmental factors, and aging.

For example, U.S. Patent No. 4, 602,246 to Jensen discloses an intruder detector apparatus in which a short wire antenna is part of an oscillator which generates an electromagnetic field surrounding the antenna. When an intruder approaches the detector he will disturb the electromagnetic field, and this disturbance will appear as a change in the capacitive reactance of the short wire antenna and will hence tune the oscillator to a new frequency. A frequency change detector is connected to the output of the oscillator and

periodically counts the frequency signal output from the oscillator in order to detect changes in oscillator frequency. The frequency change detector described is capable of detecting changes in frequency and at the same time of suppressing spurious or meaningless changes in frequency that may arise from the characteristics of a digital frequency counter employed in the frequency change detector. The person detector of U.S. 4,602,246 also employs a go, no-go decision process in order to eliminate spurious outputs from the frequency change detector caused by the drifting of the oscillator frequency. The particular decision process employed provides an output signal upon the occurrence of a predetermined number of outputs, for example four consecutive detections, from the frequency change detector, within a predetermined sequence of frequency count periods.

However, the above decision process is based on the assumption that an intruder entering the field of the antenna will cause a continuous frequency change with time. Consequently, the frequency change detector will register continuous detections when an intruder disturbs the electromagnetic field surrounding the antenna. Conversely, when there is no actual field disturbance due to an intruder, the frequency change detector will register a false output non-continuously and at random intervals. It will be seen that the above decision process distinguishes between the characteristics of a desired signal and those of random noise on the basis of the duration of the detection signal. The selection of the number of consecutive count periods in which a detection must occur then becomes a critical factor in determining the sensitivity of the person detector of Jensen. Consequently, the selection of an appropriate

number of consecutive detections will always involve a compromise between the detector sensitivity and its ability to suppress spurious responses.

Summary of the Invention

The present invention was developed with a view to providing a proximity sensor with an improved sensitivity which does not compromise its ability to suppress false sensing.

According to one aspect of the present invention there is provided a proximity sensor comprising:

sensing means for generating an electromagnetic field defining a sensing volume, said sensing means being responsive to a disturbance of said field to produce an output signal;

digital control means responsive to said output signal for measuring effective time rates of change of said disturbance whereby, in use, said digital control means can discriminate between an artificial disturbance of said field and a natural disturbance of the kind caused by environmental drift.

Preferably said sensing means comprises an electrostatic sensing element connected to an interface means for detecting small variations in effective capacitance of the sensing element caused by a disturbance of the field surrounding said sensing element, and producing said output signal in response to said detection.

Preferably said proximity sensor further comprises recalibrating means controlled by said digital control means for recalibrating said proximity sensor whereby, in use, maximum detection sensitivity to capacitance variations can be maintained.

According to another aspect of the present invention there is provided a method of sensing an object using a proximity sensor, the method comprising:

generating an electromagnetic field defining a sensing volume;

detecting a disturbance of said field;

producing an output signal in response to said detection;

measuring effective time rates of change of said using said output signal; and

processing said effective time rates of change to discriminate between an artificial disturbance of said field caused by said object in said sensing volume and a natural disturbance of the kind caused by environmental drift.

Preferably said method comprises a further step of recalibrating the proximity sensor in order to maintain maximum sensitivity when detecting a disturbance of the field.

Brief Description of the Drawings

In order that the invention can be more clearly ascertained a preferred embodiment will now be described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 illustrates schematically a preferred form of a proximity sensing system in which an embodiment of the proximity sensor can be employed;

Figure 2 is a block diagram illustrating the interconnection of the various functional blocks of a preferred embodiment of the proximity sensor;

Figure 3 illustrates graphically the relationship between capacitance and output signal of the sensing means in the proximity sensor of Figure 2;

Figure 4 is a flow chart illustrating a preferred method of operation of the sensor of Figure 2; and

Figure 5 is a more detailed circuit schematic for the sensor illustrated in Figure 2.

Description of Preferred Embodiment

In Figure 1 a preferred form of the proximity sensing system is illustrated and consists of one or more sensor units 10 and an associated monitor unit 12. Each sensor unit 10 performs sensing of its immediate environment to detect any change as a consequence of a proximity violation. The sensor unit 10 transmits all violation events to the remote monitor unit 12 which will then trigger an alarm signal. Besides acting as the alarm signalling device, the monitor unit 12 also maintains complete control over each sensor unit 10 (may control up to, for example, eight sensor units). The monitor 12 continuously monitors the status of each of the sensors 10 and is used to activate and deactivate any one or more of the sensor units as required. The monitor unit 12 is provided with a liquid crystal display for status and programming purposes, and is used to program each of the sensors 10 by a simple keyboard arrangement 16, assisted by prompting on the display 14.

Communication between the sensors 10 and their assigned monitor 12 is accomplished using (off the shelf) integrated RF transceivers. These transceivers have a typical working range of up to 300 metres in residential or light industrial environments. The transceivers are hardened to interference by hardware and protocol design.

The primary performance requirement for the sensor 10 is to continuously detect changes in its immediate environment. Such changes reflect motion and

proximity violation, which are to result in an alarm condition. In order to perform in this manner the sensor has the following functions:

A. On activation, automatically reconfigures to adapt to the external environment.

B. Monitors all environmental changes.

C. Characterises changes as either background or proximity violation.

D. On violation, transmits alarm signal until acknowledged by monitor.

E. On low battery or sensing failure, reports status to the monitor.

The unit has the further responsibility of continuously listening for a command transmission from its assigned monitor. For example, on receipt of a command it will execute the command, and on receipt of an unacknowledged alarm signal, it will attempt to retransmit the alarm signal. The sensor 10 will also discriminate between natural and deliberate interference on the RF channel, and will report attempted jamming to the monitor 12.

The primary performance requirement for the monitor 12 is the continuous monitoring of the RF communication channel. All transmissions received from the sensors 10 are processed and an alarm status must be signalled as required. To perform in this manner the monitor 12 supports the following functions:

A. Detection of attempted jamming and raising of an alarm.

B. The acknowledgement of a sensors alarm transmission.

C. Audible (piezoelectric buzzer) alarm.

D. Displays sensor ID and alarm condition.

E. Displays logging-off fault and battery status of the sensors.

The monitor has the additional responsibility of communicating command requests to a selected sensor and providing co-ordination of command selection using the mode buttons 16 and display prompts.

The proximity sensing system is designed to keep both the monitor unit and the sensor unit as small as possible and with minimum power consumption so that both units can operate continuously for up to one year before battery replacement is necessary. Both units will be light weight and dimensioned to be housed within a two part injection moulded and impact resistant plastic case, less than 130 x 80 x 15mm in size. The sensor unit can then be mounted in a recessed location, such as behind a picture frame or within a cupboard space so as to be unobtrusive. The monitor unit is also sufficiently small to be belt worn or may be permanently wall mounted.

Miniaturization of the sensor unit 10 can be implemented by reducing the circuit to three sub-assemblies, each sub-assembly being capable of single chip manufacture. These sub-assemblies are:

(i) The microprocessor and all the digital interface hardware. Selection of the 68 HC11 type processor provides all the necessary digital requirements and is currently available as a single chip.

(ii) Analog generation and processing of the detection signals. Single chip implementation is commensurate with the capabilities of the Semi-custom Raytheon array type RLA120.

(iii) RF transmitter and receiver (transceiver). Integrated RF transceivers are also currently available and may be custom designed to meet the power requirements of the sensor unit.

The RF transceiver sub-assembly will now be briefly described, whilst the micro-processor, digital interface hardware and the analogue generation and processing of a sensor unit will be described in greater detail below.

The integrated RF transceiver utilizes on/off keying and the receiver section is duty cycled for low power operation. The transmitter power is selected to be approximately 10 milliwatt and the receiver sensitivity is preferably less than 2 micro-volt. The RF transmission frequency may be selected to suit the particular operating environment and to conform to Government regulations, and could be, for example, 303.875 MHz. The transceiver antenna is preferably in the form of an "L" section and is printed onto the circuit board. This configuration achieves maximum transmission range when both the sensor and monitor are coplanar.

Data is transmitted as packets (10 millisecond duration) and received asynchronously with acknowledgement and retry. Typically, a 100 bit data packet will be transmitted, consisting of a preamble, a factory instruction code (16 bits), a user code (8 bits), a unit number (8 bits), a command/status code (16 bits) and some spare bits. The data packet is transmitted with bit stuffing, so that no more than five consecutive bits are identical. Pseudo random coding of the data (not preamble) is also performed in order to enhance the security of the transmissions. The RF transceiver interacts with the digital and analogue sub-assemblies so that most of the peripheral functions such as encoding (and quenching), data output amplification, etc., would be provided by the microprocessor and the analogue custom chip respectively. A preferred embodiment of the digital and analogue sections of the sensor unit 10 will now be described with reference to Figures 2, 3 and 4.

Referring to Figure 2 there is shown in block diagram form the various functional blocks of a preferred embodiment of the proximity sensor unit which may be used in the system of Figure 1. Essentially the sensor comprises a sensing means 20, a digital control means 22 and an RF transceiver 24. In this embodiment, sensing means 20 comprises an oscillator 26 which produces a sinusoidal signal of 10.7 MHz which is fed to a sensing element interface 28. The oscillator frequency can be selected to suit the particular application in view. In this embodiment the sensing element interface 28 is a frequency discriminating or filtering network to which the sensing element 30 is connected. The sensing element 30 is selected to be of short length relative to the wave-length of the oscillator signal so that radiation components in the electromagnetic field surrounding the sensing element are minimized and the field is principally electrostatic in nature. The geometry of the sensing element 30, that is the physical arrangement of the conductors of the element, will determine the angular sensitivity pattern of the sensor, whereas size and frequency of operation will determine the sensing volume and the nature of the distance dependence ($1/r^3$ for electrostatic field, $1/r^2$ for induction field, $1/r$ for radiation field, where r is distance from the element).

The sensing element preferably consists of a conductive ribbon which has a sensing volume in the shape of a distorted cylinder, having the ribbon extending along the longitudinal axis of the cylinder. When an object enters the sensing volume of the sensing element 30, the electrostatic field surrounding the element is disturbed and will cause a variation in the impedance of the sensing element, which is essentially capacitive in nature. Because of the distance dependence of the electrostatic field surrounding the sensing element, the nearer the object approaches the sensing element the

larger will be the change in effective capacitance of the sensing element with changes in the distance of the object from the sensing element. The sensing element interface 28 is designed to enable detection of small variations in the effective capacitance of the sensing element and to produce an output signal proportional to the changes in effective capacitance.

The sensing means 20 further comprises a voltage controlled capacitor 32 which is connected to the sensing element interface 28 for controlling the sensitivity of the interface to small variations in effective capacitance of the sensing element. Preferably the voltage controlled capacitor 32 is controlled by a programmable voltage source 34 which is controlled by the logic control means 22 for automatically calibrating and recalibrating the sensing means 20 in accordance with the particular environment in which it is located. Since the objective is to sense small electrostatic field perturbations which result in variations in the effective capacitance of the sensing element 30, the use of a high Q-factor circuit (that is, a resonant circuit) in the sensing element interface 28 offers the possibility of sensitivity enhancement. In particular, series resonance offers the advantage of operation at a low effective impedance, thus increasing noise and interference immunity.

Figure 3 illustrates graphically the relationship between the amplitude of the output signal of sensing means 20 and variation in the effective capacitance of the sensing element 30 which is connected to the interface 28 to form a tuned circuit. The sensing means 20 of Figure 1 is tuned via the voltage controlled capacitor 32 to operate on a side of the resonance peak. The side of the resonance peak with the steepest gradient is selected in order to provide maximum sensitivity to changes in effective capacitance of the sensing element.

Control of the voltage controlled capacitor 32 and the signal offset enables any point of the resonance curve to be visible to the digital control means 22 at any one time, assuming the resonance peak is monotonic, and capacitance control is sufficient to find the resonance point. Calibration and recalibration of the sensing means 20 will be described in further detail below.

The output signal of sensing means 20 is amplified by pre-amplifier 36 and the amplitude variations of the signal are then detected by detector 38. Detector 38 is effectively a simple amplitude modulation detector which separates the capacitance variation signal from the oscillator (10.7 MHz) carrier signal. The capacitance variation signal output of detector 38 is then further amplified through the gain stage 40 before being fed to the digital control means 22. The offset of the gain stage 40 can be controlled by a second programmable voltage source 42 in order to maintain the analogue signal between the maximum and minimum signal levels that can be accepted by the digital control means 22. The programmable voltage source 42 is also under the control of digital control means 22.

Digital control means 22 is provided with an analogue to digital converter 44 for converting the analogue input signal into digital format for further processing by other functional blocks within the control means 22. The digital output signal of the A/D converter 44 is employed essentially in two ways: Firstly the digital signal is employed by the digital control means to measure effective time rates of change of variations in the digital signal, which are representative of variations in the effective capacitance of the sensing element 30. Secondly, the digital control means continually monitors the output of the A/D converter in order to detect whether the minimum or maximum value has

been exceeded, and will set a recalibration flag if required in order to trigger recalibration of the sensing means 20.

Digital control means 22 uses the time rates of change measurements to discriminate between artificial disturbances of the fields surrounding the sensing element and natural disturbances caused by environmental changes or component drift.

Processing of the digital signal to obtain the time rates of change is performed in this embodiment using a cascade of finite impulse response (FIR) digital filters 48 which are configured as low-pass filters. The output of each of the FIR filters is compared with preset alarm thresholds by the alarm characterization means 50 in order to determine whether an alarm condition exists. The alarm characterization means 50 will set an alarm if any one of the output signals from the FIR filters 48 exceeds the corresponding threshold. Interlock means 52 ensures that once an alarm condition is detected the digital control means 22 does not attempt to recalibrate the sensing means 20, so that sensing means 20 remains locked to the sensitivity at which the alarm condition was detected. The alarm signal will then be transmitted to the associated monitor unit by the RF transceiver 24 as previously described. Operation of the sensor illustrated in Figure 2 will now be described with reference to Figure 4.

On start-up the logic control means 22 calibrates the sensing means 20 in order to set the operating point. Following initialization of all of the digital hardware components, the calibration means 46 ramps the voltage of programmable voltage source 34 through its complete range in order to sweep the voltage controlled capacitor 32, and simultaneously monitors the output from A/D converter 44 in order to find the resonance point of the interface 28. If resonance is not

achieved within a preset voltage window of the A/D converter 44, calibration means 46 can adjust the programmable voltage source 34 of interface 28 and the programmable voltage source 42 of the gain stage 40 until the resonance peak is found. It then selects the most sensitive (steepest) side of the resonance peak and sets the hardware to this configuration. At this stage, the digital control means 22 also computes the recalibration co-efficients.

Once calibration has been completed at start-up, the sensor is ready for automatic sensing of any disturbance of the field surrounding sensing element 30. However, even during normal operation of the sensor following start-up, logic control means 22 periodically recalibrates the sensing means 20 in order to maintain maximum sensitivity and to provide automatic adjustment to background changes caused by environmental drift or control voltage leakage. The recalibration means 46 continually monitors the digital output from the A/D converter 44 in order to detect when the operating point results in an analogue signal from the gain stage 40 near the maximum or minimum conversion value of the A/D converter 44. When it detects such a change in the signal, the recalibration means 46 measures the signal divergence from mid value and then from this computes the corresponding capacitance change. It then uses the value of the capacitance change to set the sensing means 20 to a new operating point that results in a signal within the conversion window of the converter 44. It then again measures the signal divergence from mid value and adjusts the recalibration co-efficients accordingly.

The digital control means 22 also continuously measures changes in amplitude of the analogue signal and determines if the changes are a result of back-ground effects or a proximity violation. It does this by measuring effective time derivatives or time rates of

change of the signal changes and compares the values obtained with preselected stored threshold values, which characterize the particular proximity violations the sensor is designed to sense. The threshold values are stored in memory and are preset at the manufacturing stage, and in some cases may be adjusted by the end user to adapt the sensor to a particular sensing environment.

The effective time rates of change of the signal variations are measured by digital filtering of the signal in the time domain using multiple FIR filters. In effect this is done by convolving the digital signal from the A/D converter 44 with the impulse response of each of the FIR filters 48 over different time scales. In this particular embodiment four FIR filters are employed cascaded an octave apart with time scales of 80 milliseconds, 640 milliseconds, 5.12 seconds and 40.96 seconds respectively using a sampling period of 10 milliseconds. The FIR filters are configured as low-pass filters and effectively filter out trends in the signal amplitude variations over the different time scales of the respective filters. The effective time rates of change of the signal variations will be directly proportional to the time rates of change of the effective capacitance of the sensing element 30. The time rates of change of the capacitance variations are in turn related to the velocity of a moving object in the proximity of the sensing element or the rate of change of environmental drifts (temperature, humidity, aging of components, etc.). Normally the latter are much slower than the former and accordingly discrimination on the basis of the magnitude of the rates of change can be performed.

In this embodiment only the first time derivatives of the capacitance variations are measured, however relatively simple modifications are required to the digital filtering in order to obtain the second time

derivatives (which are related to the acceleration of an object moving within the sensing volume of the sensing element), if required. In this manner, a proximity violation can be characterized to any degree of accuracy required by selecting appropriate response times for the FIR filters.

A preferred embodiment for the hardware implementation of the sensor illustrated in Figure 2 will now be described with reference to Figure 5:

Figure 5 is a circuit schematic for the preferred implementation of the manufacturing prototype of the sensor illustrated in Figure 2. In this embodiment the digital control means 22 is implemented using an available integrated circuit processor, namely the 68 HC11 processor. The 68 HC11 is provided with its own on-board A/D conversion and the CPU performs all of the control operations including calibration and recalibration, FIR filtering, alarm characterization and the generation of all of said control and switching signals.

Selection of the 68HC11 processor ensures that the digital control means 22 occupies minimum space on the sensor printed circuit board. However, it will be obvious to those skilled in the electronics art that the various control functions and filtering performed by the 68 HC11 can also be performed by alternative hardware configurations. For example, all of the FIR filtering is performed by software processing of the A/D converted analogue signal from the final gain stage 40. However, the FIR filters could alternatively be implemented in hardware using digital delay lines with tapping points and multipliers arranged according to the common digital transversal filter configuration. However, such a hardware implementation of the FIR filters would be inefficient both from the point of view of space occupied and power consumed. A much more efficient implementation

is the software version, which also provides increased flexibility since the number and value of the filter weights can be adjusted as required.

As noted above, the FIR filter response characteristics have been selected to provide low-pass filtering in the time domain over different time scales, so that the output of each of the FIR filters effectively provides a measure of the first derivative of the capacitance variations as detected by the analogue circuitry. The FIR low-pass digital filters effectively filter out high frequency noise and look for trends in the signal as it changes over time. The filter response characteristics and alarm thresholds can be custom designed for a particular sensing environment so that the system ignores background capacitance variations caused by, for example, changes in air temperature and humidity due to fluctuations in the air conditioning, although these types of background variations will to some degree be compensated for automatically by the sensor recalibration. Obviously, the use of FIR filters is only one of several techniques that may be employed in the digital control means 22 in order to measure the effective time rates of change of the capacitance variations sensed by the sensing element 30.

It is the preferred technique because the FIR filters are relatively simple to implement and are flexible.

The 68 HC11 microprocessor clock is slaved to the crystal oscillator 26 via flip flop 54. The oscillator frequency of 10.7 MHz is harmonically related to the clock frequency of the processor, however a separate unrelated oscillator can be provided for the processor if necessary. The oscillator signal is fed to the sensing element interface 28 via a transformer 56. The OSCOFF signal from the processor provides a DC off-set for the oscillator signal, and the OSCQUENCH

signal provides a means of initiating and sustaining oscillator action. In this embodiment the sensing element interface 28 is in the form of an inductive resonance bridge network chosen because the sensing element is primarily capacitive. The bridge circuit has the advantage of series resonance noted above. However, it is obviously not the only suitable implementation for the interface 28. Any filter with a sufficient frequency roll-off would perform a similar function to the bridge in acting as a discriminator.

Tuning of the sensing element interface 28 is achieved by means of the voltage control capacitor network 32 which comprises three varactor diodes V1, V2 and V3. The capacitance of varactor V1 is controlled by the programmable voltage source 34 to provide fine control of the capacitance of network 32. The programmable voltage source 34 has been linearized by the use of opamps and pumps the charge of the varactor diode V1 up or down in response to the DISCHARGE and CHARGE signals from the processor 22. The COARSE signal from the processor 22 controls the capacitance of varactor diode V2 and provides coarse control of the capacitance of network 32. The varactor voltage can be monitored, if required, via the A/D converter of the 68 HC11 processor in order to provide closed loop control of the varactor voltage. The OFF-SET 1 and OFF-SET 2 signals from the processor 22 enable adjustment of the DC off-set for the varactor diode V3 which provides a third degree of control over the capacitance of network 32 and hence of the tuning of the interface 28.

The sensing element 30 is preferably in the form of a conductive ribbon as previously described. However, the physical implementation of the sensing element may take any form depending on the application in view. For example, the sensing element may be in the form of capacitive plates, or in the form of a printed

circuit pattern designed to achieve a particular sensing volume and configuration. The shape and orientation of the electrostatic field surrounding various configurations of conductors is relatively well understood and can be applied to the design of the sensing element in order to achieve the required sensing volume.

The output from the interface network 28 is band-pass filtered by an SFE 10.7 MHz crystal filter in order to eliminate frequency signals outside the narrow band centred on the oscillator frequency. The 10.7 MHz signal is then amplified in preamplifier 36 and rectified in the detector 38 by a simple AM diode detector using diode D1. The RECOFF signal from the processor 22 provides gating to power down the detector 38.

The output of the detector 38 is effectively the amplitude modulations of the oscillator carrier signal caused by capacitance variations of the sensing element 30 and component drift caused by aging and environmental factors. This signal is fed to the final gain stage 40 where it is further amplified before being fed to the processor 22. Prior to amplification in the final gain stage 40, the analogue signal is separated into two feed paths controlled by the synchronous SIG and SIG(Bgd) signals from the processor 22 to enable the subtraction of background noise and interference from the main signal in order to improve system immunity to external effects. The processed analogue signal is accessed by the A/D converter of processor 22 both before and after the final gain stage to provide COARSE and FINE steering for the varactor control, and the amplifier off-set of the gain stage 40.

Improved noise immunity and lower power consumption can be achieved by pulse modulation of the oscillator signal and synchronous detection by the processor 22. This enables the processor 22 to further

reject spurious noise events which may appear in the analogue signal. Power for the sensor is provided by a single 3.65 volt lithium cell in power supply 58. Power fluctuations can be monitored by the processor 22 for diagnostic and correction purposes. On-board voltage regulation and low battery warning detection is also provided. The operating voltage of the sensor is 3 volts with an anticipated operating current for the analogue, digital and RF assemblies of several milliamps. Naturally, the RF section of the sensor may be dispensed with if hardware connection of the sensor to its associated monitor can be tolerated. Various diagnostic LEDs (not shown) may be provided in the sensor circuit, and the software adapted in order to display relevant control parameters on-board. Detection reliability can be enhanced by the use of a reference capacitor on-board to separate component induced variations in the detected signal from environmentally induced variations. Similar benefits may also result from using a bank of multiple sensing elements.

The use of multiple sensing elements can also provide the sensor with a simple direction finding capability. By appropriate orientation of a plurality of sensing elements, spatial discrimination can be effected by processing of the sum and difference signals from each of the plurality of sensing elements. Correlation of the signal variations from each of a plurality of sensing elements by the processor 22 would enable the sensor to distinguish between global and local disturbances and thus enhance the suppression of false alarms.

It will be evident to persons skilled in the art that a security proximity system employing the above proximity sensor provides a number of distinct advantages over existing systems and devices. For example, there is reduced radio frequency interference since the detection signal is sinusoidal rather than pulsed. Furthermore,

the proximity sensor offers enhanced time resolution since continuous acquisition of system and environmental information is achieved, as opposed to a pulse method which only acquires information during the pulse period. The self-tuning capability of the sensing element interface under the control of the digital control means 22 provides automatic calibration and recalibration, and ensures that maximum sensitivity and resolution is maintained. Measurement of the time rates of change of signal variations and employing adaptive alarm characterisation also provides improved sensor discrimination between true and false proximity violations.

The proximity sensor according to the present invention is not limited to the above described application in a security system, but may find application in other situations where accurate non-contact sensing of small proximity variations and other variations is required. For example, it has been suggested that the sensor may find application in critical surgical procedures in which the sensor is used to generate a sensing volume surrounding the exposed area of the body which is being operated on. For example, when using a laser scalpel during brain surgery, the exposed area of the brain can be protected by the proximity sensor so that the intrusion of the laser beam into the sensing volume of the sensor would automatically shut down the power to the laser scalpel.

From the above description of a preferred embodiment of the proximity sensor it will be evident that various modifications and alterations may be made, other than those already described, without departing from the basic concepts of the present invention. All such modifications and alterations are to be considered

within the scope of the invention, the nature of which is to be determined from the foregoing description and the appended claims.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A proximity sensor comprising:

sensing means for generating an electromagnetic field defining a sensing volume, said sensing means being responsive to a disturbance of said field to produce an output signal;

digital control means responsive to said output signal for measuring effective time rates of change of said disturbance whereby, in use, said digital control means can discriminate between an artificial disturbance of said field and a natural disturbance of the kind caused by environmental drift.

2. A proximity sensor as claimed in Claim 1, wherein said sensing means comprises an electrostatic sensing element connected to an interface means for detecting small variations in effective capacitance of the sensing element caused by a disturbance of the field surrounding the sensing element, and producing said output signal in response to said detection.

3. A proximity sensor as claimed in Claim 1, wherein said digital control means comprises analogue to digital converting means for converting said output signal to a digital signal; and, digital filtering means for filtering said digital signal in order to measure said effective time rates of change of said disturbance.

4. A proximity sensor as claimed in Claim 3, wherein said digital filtering means comprises a cascade of digital filters configured as low-pass filters for filtering said digital signal in the time domain, each filter response characteristic being selected to measure different time rates of change of said digital signal.

5. A proximity sensor as claimed in Claim 4, wherein said digital control means further comprises alarm characterisation means for comparing said time rates of change measured by the digital filters with

preselected threshold values, said threshold values being preselected as characteristic of proximity violations caused by artificial disturbance of said field.

6. A proximity sensor as claimed in Claim 2, wherein said sensing means further comprises means for adjusting said interface means to obtain maximum sensitivity when detecting said small variations in effective capacitance whereby, in use, changes in magnitude of said output signal produced in response to said detected capacitance variations can be maximized in a particular sensing environment.

7. A proximity sensor as claimed in Claim 6, wherein said digital control means further comprises means for recalibrating said proximity sensor in response to natural disturbances of the kind caused by environmental drift, said recalibrating means being responsive to said changes in magnitude of the output signal to control said adjusting means whereby, in use, maximum sensitivity of said interface means can be maintained.

8. A method of sensing an object using a proximity sensor, the method comprising:

generating an electromagnetic field defining a sensing volume;

detecting a disturbance of said field;

producing an output signal in response to said detection;

measuring effective time rates of change of said disturbance using said output signal; and

processing said effective time rates of change to discriminate between an artificial disturbance of said field caused by said object in said sensing volume and a natural disturbance of the kind caused by environmental drift.

9. A method as claimed in Claim 8, wherein said step of generating an electromagnetic field comprises driving an electrostatic sensing element with a sinusoidal signal; and, said step of detecting a disturbance of said field comprises detecting small variations in effective capacitance of said sensing element.

10. A method as claimed in Claim 9, wherein said step of producing said output signal comprises detecting amplitude modulations of said sinusoidal signal caused by said small variations in effective capacitance of the sensing element, and amplifying said amplitude modulations to produce said output signal.

11. A method as claimed in Claim 10, wherein said step off measuring the effective time rates of change of said output signal comprises converting said output signal into a digital signal; and, filtering said digital signal in the time domain to obtain a measure of said effective time rates of change.

12. A method as claimed in Claim 11, further comprising the step of comparing the effective time rates of change with preselected threshold values, said threshold values being preselected as characteristic of proximity violations caused by artificial disturbance of said field.

13. A method as claimed in Claim 9, further comprising the step of adjusting the sensitivity of the proximity sensor for detecting said small variations in effective capacitance whereby, in use, changes in magnitude of said output signal produced in response to said capacitance variations can be maximised in a particular sensing environment.

14. A method as claimed in Claim 13, further comprising the step of recalibrating the proximity sensor in response to natural disturbances of the kind caused by

environmental drift whereby, in use, maximum sensitivity for detecting said capacitive variations can be maintained.

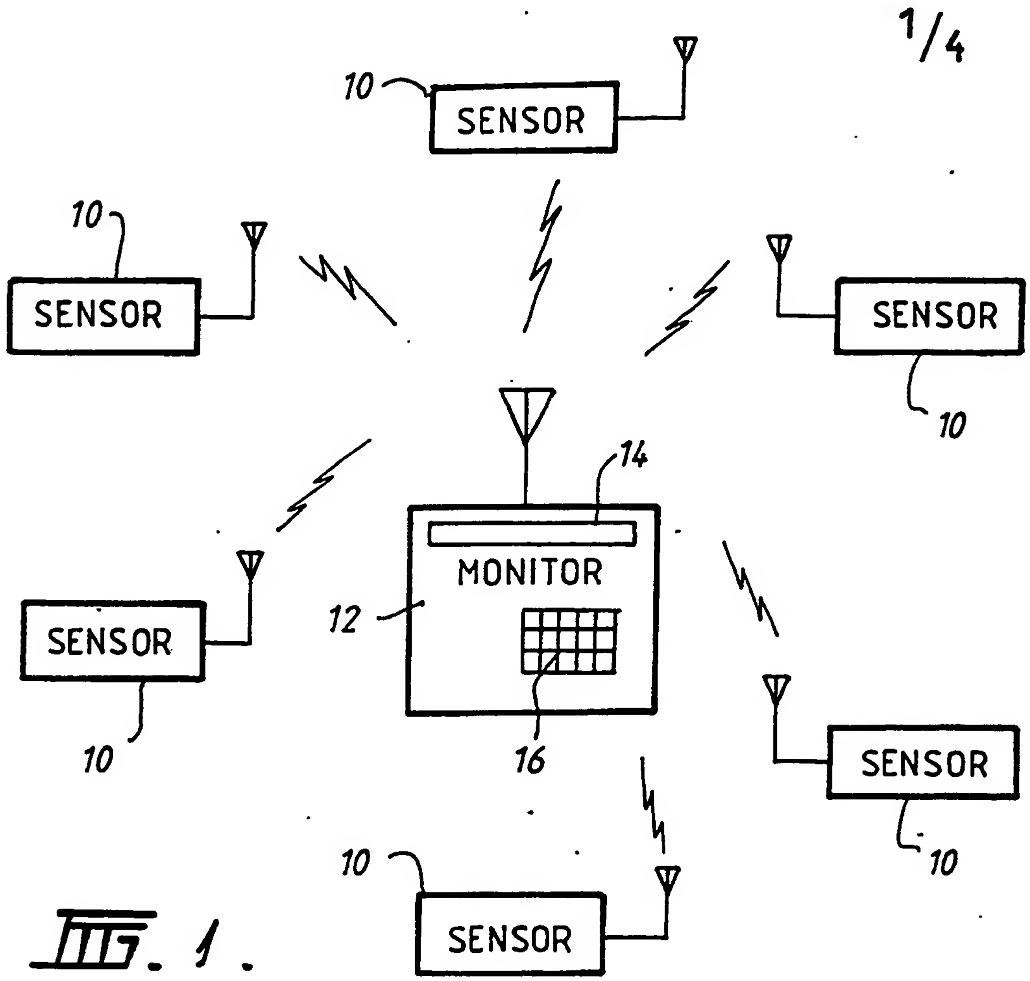
SENSOR
SENSOR
SENSOR
SENSOR
SENSOR
SENSOR
MONITOR
10
12
14
16

FIG. 1.

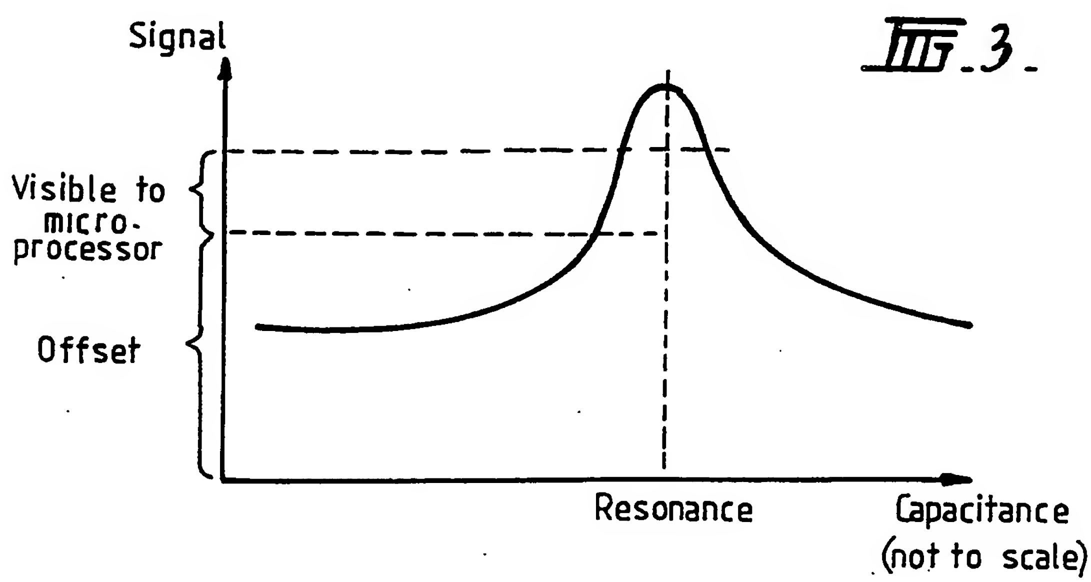
Signal
Visible to micro-processor
Offset
Resonance
Capacitance (not to scale)

FIG. 3.

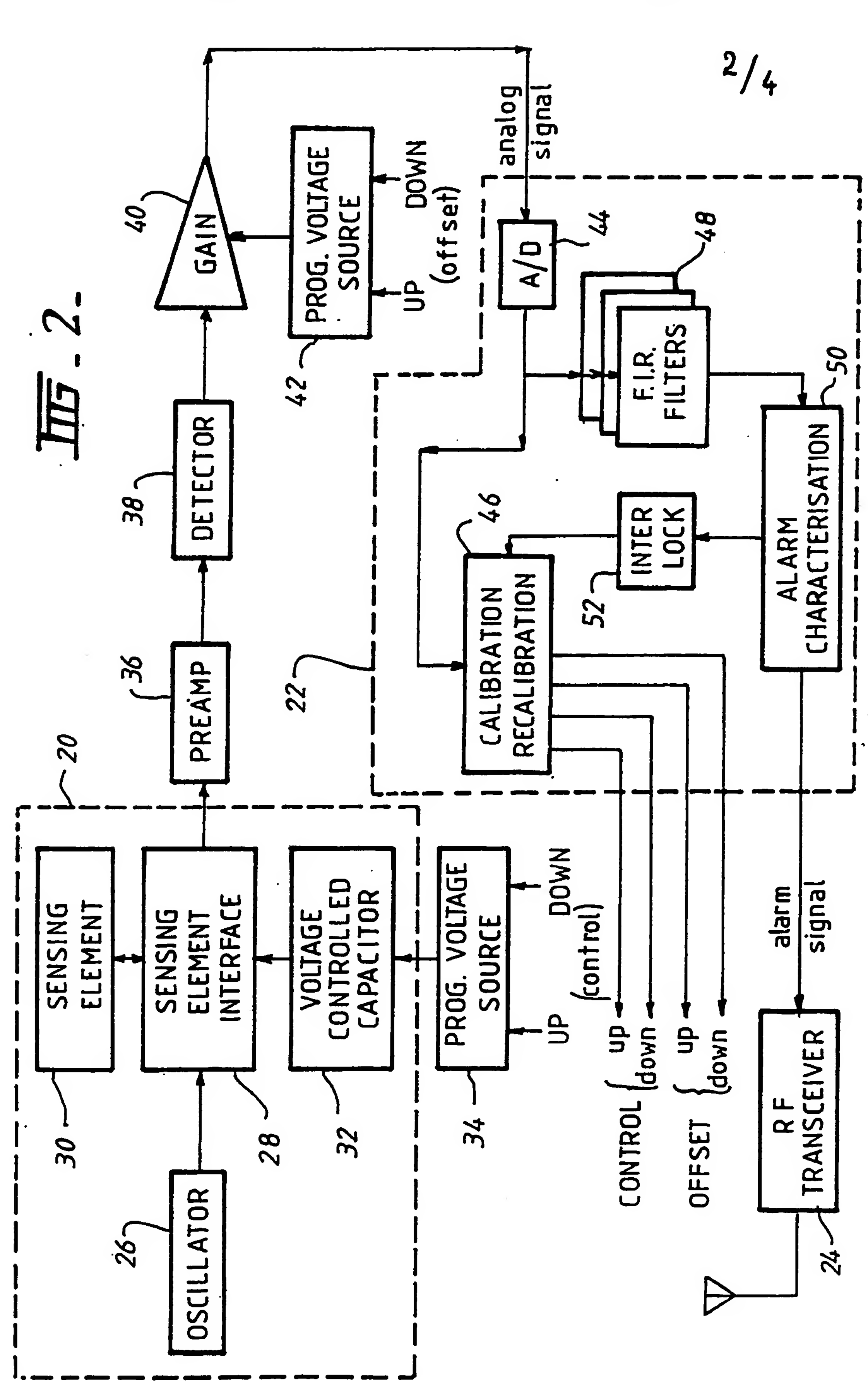
OSCILLATOR
26
SENSING ELEMENT
30
SENSING ELEMENT INTERFACE
28
VOLTAGE CONTROLLED CAPACITOR
32
PROG. VOLTAGE SOURCE
34
UP
DOWN
(control)
20
PREAMP
36
DETECTOR
38
GAIN
40
PROG. VOLTAGE SOURCE
42
UP
DOWN
(offset)
analog signal
A/D
44
F.I.R. FILTERS
48
ALARM CHARACTERISATION
50
INTER LOCK
52
CALIBRATION RECALIBRATION
46
22
CONTROL
up
down
OFFSET
up
down
alarm signal
RF TRANSCEIVER
24

FIG. 2.

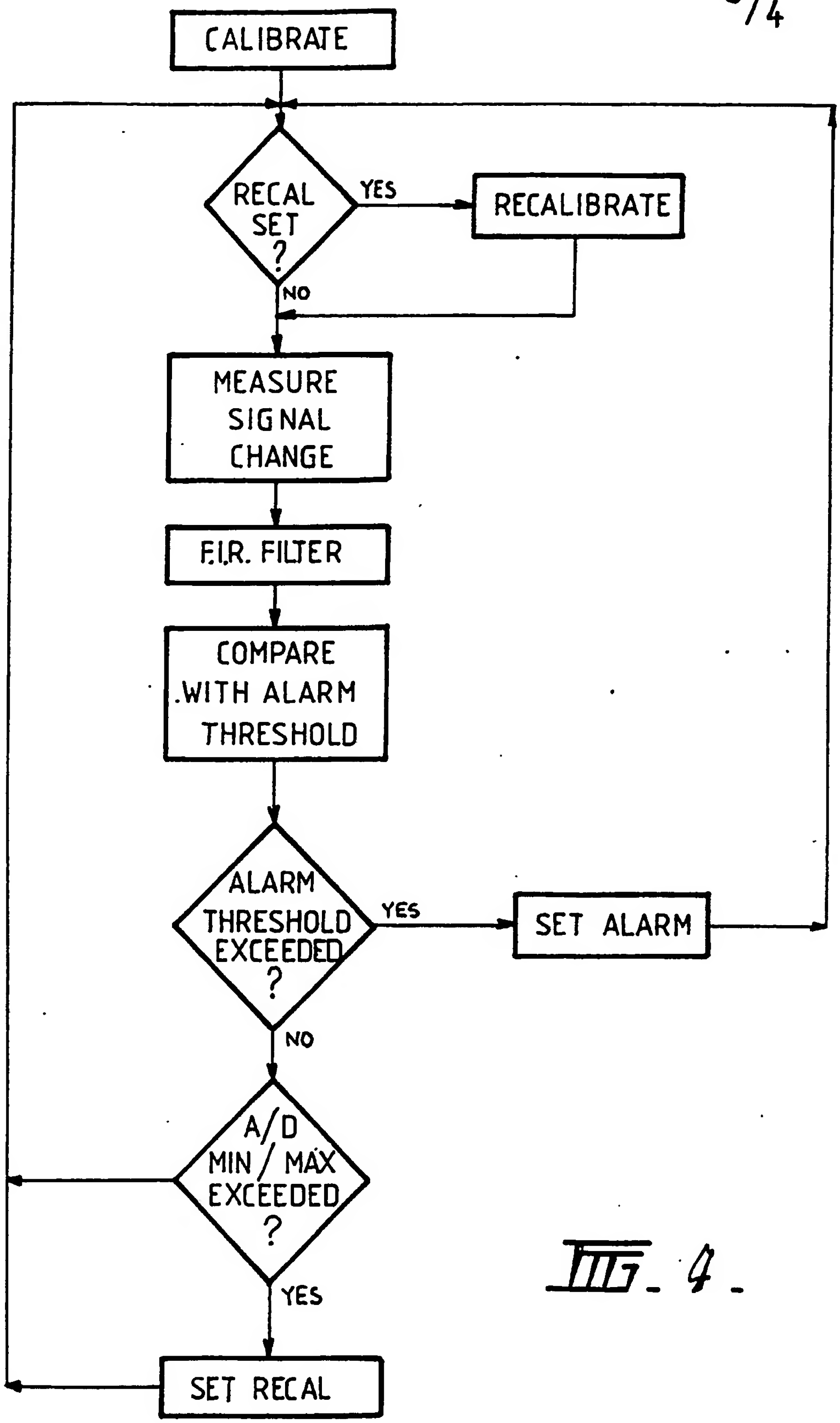
CALIBRATE
RECAL SET ?
YES
RECALIBRATE
NO
MEASURE SIGNAL CHANGE
F.I.R. FILTER
COMPARE WITH ALARM THRESHOLD
ALARM THRESHOLD EXCEEDED ?
YES
SET ALARM
NO
A/D MIN / MAX EXCEEDED ?
YES
SET RECAL

FIG. 4.

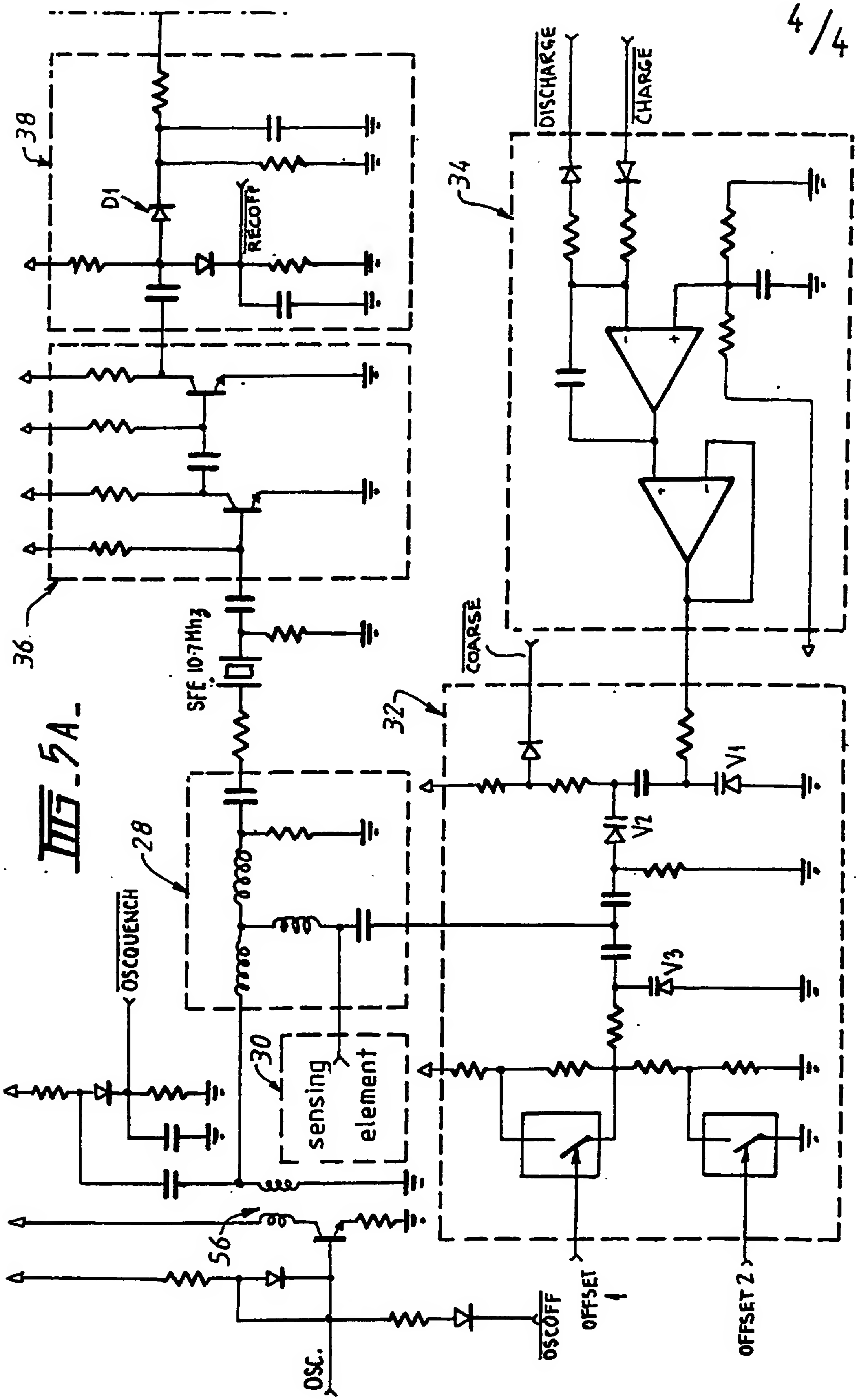
38
D1
RECOFF
34
DISCHARGE
CHARGE
36
SFE 10.7MHz
32
COARSE
V1
V2
V3
28
OSCQUENCH
30
sensing element
56
OSC.
OSCOFF
OFFSET 1
OFFSET 2

FIG 5A.

INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 88/00363

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.[4] G08B 29/00, 13/24, G01B 7/08, G01P 13/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	G08B 29/00, 13/22, 13/24, 13/26, G01B 7/08, G01P 13/00, 21/00, G01S 17/02

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	DE,A, 3526341 (SIEMENS AG) 29 January 1987 (29.01.87)	(1,2,8,9)
A	US,A, 4602246 (JENSEN) 22 July 1986 (22.07.86)	
A	US,A, 4016529 (INUZUKA) 5 April 1977 (05.04.77)	
A	US,A, 4063447 (MATHISON) 20 December 1977 (20.12.77)	
P,A	US,A, 4721945 (MAKI) 26 January 1988 (26.01.88)	
A	AU,B, 53440/79 (533426) (S.A. METAFIX, S.A. TREFIL-UNION) 12 June 1980 (12.06.80)	

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
13 December 1988 (13.12.88)	22 DECEMBER 1988 (22.12.88)
International Searching Authority	**Signature of Authorized Officer**
Australian Patent Office	R. MURRAY

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL APPLICATION NO. PCT/AU 88/00363

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members		
US 4602246	US 4536747	US 4638496	
AU 53440/79	AR 225906 EP 12092 IN 153377 US 4420745	BR 7907900 ES 486395 JP 55123794 ZA 7906442	CA 1130885 FR 2443683 MX 147487
US 4016529	DE 2519417	JP 50142057	

END OF ANNEX